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Survey of Aerothermodynamics Facilities Useful for the Design of Hypersonic Vehicles Using Air-Breathing Propulsion

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The dream of producing an air-breathing, hydrogen fueled, hypervelocity aircraft has been before the aerospace community for decades. However, such a craft has not yet been realized, even in an experimental form. Despite the simplicity and beauty of the concept, many formidable problems must be overcome to make this dream a reality. This paper summarizes the aero/aerothermodynamic issues that must be addressed to make the dream a reality and discusses how aerothermodynamics facilities and their modern companion, real-gas computational fluid dynamics CFD can help solve the problems blocking the way to realizing the dream.

The approach of the paper is first to outline the concept of an air-breathing hypersonic vehicle and then discuss the nose-to-tail aerothermodynamics issues and special aerodynamic problems that arise with such a craft. Then the utility of aerothermodynamic facilities and companion CFD analysis is illustrated by reviewing results from recent United States publications wherein these problems have been addressed. Papers selected for the discussion have been chosen such that the review will serve to survey important U.S. aero/aerothermodynamic real gas and conventional wind tunnel facilities that are useful in the study of hypersonic, hydrogen propelled hypervelocity vehicles.

A hypervelocity, hydrogen fueled, air-breathing vehicle has a slender side view and sharp leading edges on its nose and entrance to its propulsion module, known as a scramjet (short for supersonic combustion ram jet). The forebody in front of the scramjet module is generally long and serves as a compression surface for the air entering the scramjet inlet. The nose of the craft creates a body shock wave which at optimum cruise, just touches the front lip of the scramjet inlet. In this way, the air captured in the body shock is fed into the scramjet after being compressed and shock-heated. Hydrogen is injected into the scramjet combustor, energy of combustion is released and the products of combustion exit the chamber onto the aft of the aircraft. This portion of the craft serves as half-bell of an expansion nozzle and its design is critical to the installed performance of the scramjet.

The design of the vehicle's nose and forebody can be accomplished with the aid of modern real-gas CFD and validated in large shock tunnels such as the Ames 16 inch shock tunnel or the Calspan Large Energy National Shock Tunnel LENS facility. Validation also can be accomplished in conventional high speed wind tunnels such as those in the NASA Langley Hypersonic Facility complex. A brief discussion of the LENS and Ames 16 inch tunnels can be found in reference 1 and a discussion of the Langley facilities can be found in references 2 - 4. A key issue is one of heat transfer to the nose of the vehicle and the windward compression ramp, but modern, validated CFD can accommodate this with ease. The next problem is that of the fluid dynamics and real-gas heat transfer for the body shock/scramjet inlet shock interaction. Here, the role of real-gas CFD and the GARCIT T5 piston-driven shock tunnel comes to bear as described in reference 5. Aerothermodynamic facilities can play an important role in scramjet testing. As described in reference 6, and summarized in the present paper, large shock tunnels such as the Ames 16 inch facility have been used to conduct semi-direct free jet scram jet testing

at simulated flight conditions in the Mach 12 - 16 regime. Modern CFD and conventional hypersonic wind tunnels have been used to study the nozzle expansion problem. The results from the Ames 3.5 ft hypersonic facility involving the study of scramjet expansion ramps described in reference 7 will be summarized in the present paper, illustrating progress on this problem.

Finally, all of this has to be put together into one, controllable vehicle. This brings to bear the issue of air-frame propulsion integration and controls. The present paper addresses these issues by summarizing the results from references 2 - 4.

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